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Application the P-Q Algorithm Method and Fuzzy Logic Controller by using a Multilevel Inverter as an Active Power Filter shunt

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***Abstract*—This article presents two methods for the compensation of harmonics generated by a nonlinear load. The first is the P-Q algorithm method. The second is the controller by fuzzy logic. Both methods are applied to a Parallel Active Power Filter (Active Power Filter shunt - APFs) based on a three-phase voltage converter at five levels NPC topology. In calculating the harmonic currents of reference, we use the algorithm**

P-Q and pulse generation, we use the intersective PWM. For flexibility and dynamics, we use fuzzy logic. The results give us clear that the rate of Harmonic Distortion issued by fuzzy logic is better than P-Q algorithm.

Key-Words— APFs, Pulse Width Modulation (PWM), THD, Fuzzy logic controller, P-Q algorithm.

I. Introduction

The increasing use of control systems based on power electronics in industry involves more and more disturbance problems in the level of the electrical power supply networks [1], [2]. Non-linear electronic components such as diode/thyristor rectifiers, switched mode power supplies, arc furnaces, incandescent lighting and motor drives are widely used in industrial and commercial applications. These non-linear loads create harmonic or distortion current problems in the transmission and distribution network. The harmonics induce malfunctions in sensitive equipment, over voltage by resonance and harmonic voltage drop across the network impedance that affect power quality [3].

Researchers around the world are developing an active power filter shunt (APFs) to improve the power quality without the disadvantages of passive filters described in [4], [5]. The power switching devices is driven with specific control strategy to produce current that is able to compensate for harmonic and poor power factor load.

II. Active Power Filter shunt

Active Power Filter shunt (APFs) is a power electronics device based on the use of power electronics inverters (Fig.1). The shunt active power filter is connected in a common point connection between the source of power system and the load system which present the source of the polluting currents circulating in the power system lines. This insertion is realized via low pass filter such as, L, LC or LCL filters [6].

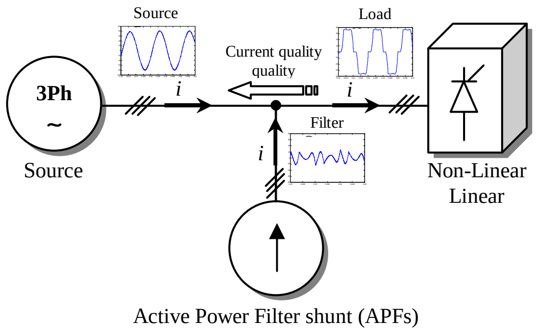

Fig. 1 Active Power Filter shunt principle schematics

The most important objective of the APF is to compensate the harmonic currents due to the non-linear load. Exactly to sense the load currents and extracts the harmonic component of the load current to produce a reference current as shown in fig. 2, The reference current consists of the harmonic components of the load current which the active filter must supply [7], [8]. APFs is controlled to supply/extract compensating current to/from the utility Point Common Coupling (PCC).

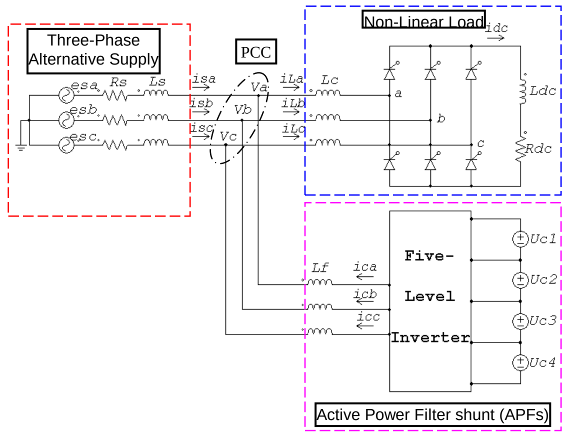

Fig. 2 Equivalent schematic of APFs five levels

III. Multilevel Inverter Illustration

A. *Modeling of Three-Phase Inverter a Five-Level NPC Topology*

The topology modelled in this study is the voltage inverter three phase five-level topology NPC (Neutral Point Clamp) [9], [10]. Fig. 3 shows the voltage three-phase five-level NPC topology inverter. The symmetry of three-phase five-level inverters can model them by arm [11], [12], [13].

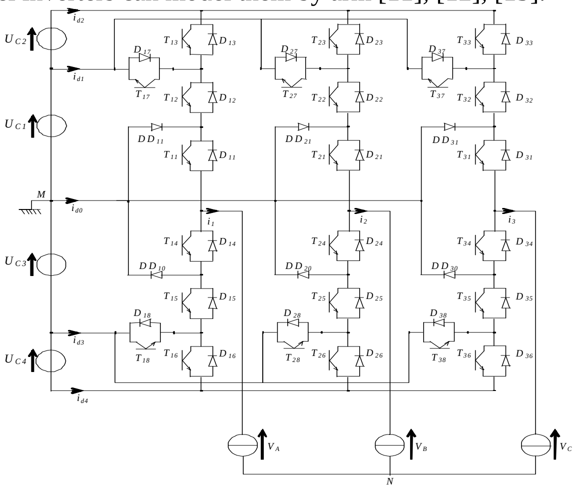

Fig. 3 Three-Phase Inverter a Five-Level NPC Topology

To avoid short-circuit voltage sources by conducting several switches, and the inverter is completely controllable, we adopt an additional control, the optimal control is defined as follows:

$$\begin{cases} F_{k4} = 1 - F_{k2} \\ F_{k5} = 1 - F_{k1} \\ F_{k6} = 1 - F_{k3} \end{cases}, \qquad (1)$$

For the arm k, the connection functions of half arm expressed by means of connection functions of the switches as follows where $k = 1, 2, 3$:

$$\begin{cases} F_{k1}^{b} = F_{k1}.F_{k2}.F_{k3} \\ F_{k0}^{b} = F_{k4}.F_{k5}.F_{k6} \end{cases}, \qquad (2)$$

Connect functions for switches in parallel are defined as follows:

$$\begin{cases} F_{k7} = F_{k1}F_{k2}(1 - F_{k3}) \\ F_{k8} = F_{k4}F_{k5}(1 - F_{k6}) \end{cases}, \qquad (3)$$

Potentials of nodes A, B and C of Three phase five-level inverter relatively to the middle point M in the case $U_{C1} = U_{C2} = U_{C3} = U_{C4} = U$ are given by the following system:

$$\begin{bmatrix} V_{AM} \\ V_{BM} \\ V_{CM} \end{bmatrix} = \begin{bmatrix} F_{17} + 2F_{11}^{b} - F_{18} - 2F_{10}^{b} \\ F_{27} + 2F_{21}^{b} - F_{28} - 2F_{20}^{b} \\ F_{37} + 2F_{31}^{b} - F_{38} - 2F_{30}^{b} \end{bmatrix} U_C, \qquad (4)$$

The voltages across the load are given by the following system:

$$\begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \left\{ \begin{bmatrix} F_{17} + 2F_{11}^{b} - F_{18} - 2F_{10}^{b} \\ F_{27} + 2F_{21}^{b} - F_{28} - 2F_{20}^{b} \\ F_{37} + 2F_{31}^{b} - F_{38} - 2F_{30}^{b} \end{bmatrix} U_C \right\}, \qquad (5)$$

B. *The four carriers sinusoidal pulse width modulation strategy*

In this section we will present the strategy triangulo-sinusoidal with four triangular bipolar carriers [13], [14] (Fig.4). Where we use four triangular carriers bipolar (U_{p1}, U_{p2}, U_{p3}, U_{p4}) dephased one quarter of the period (*Tp/4*) one relative to another. As for the triangulo-sinusoidal command at a one carrier, this strategy is characterized by the modulation index *m*.

$$m = \frac{f_{pm}}{f_m}, \qquad (6)$$

$$r = \frac{V_m}{U_{pm}}, \qquad (7)$$

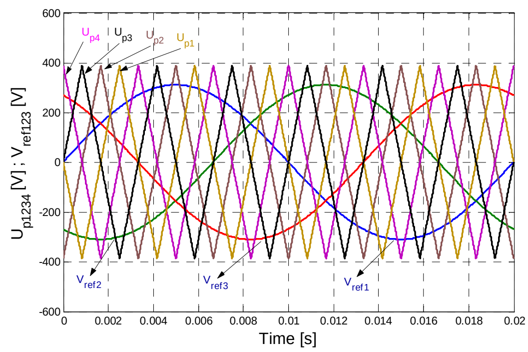

Fig. 4 Different signals for the four carriers sinusoidal pulse width modulation strategy (m = 6, r = 0.8)

IV. Method of instantaneous power

A. *Instantaneous active and reactive powers*

This method of identification of harmonic currents, simpler is to eliminate the dc component of instantaneous active and reactive power which is relatively easy to achieve [15]. Respectively denote the vectors of voltages at the connection point [v_s] and load currents [i_c] a balanced three-phase system by [15], [16], [17]:

$$[v_s] = \begin{bmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix} \quad \text{and} \quad [i_c] = \begin{bmatrix} i_{ca} \\ i_{cb} \\ i_{cc} \end{bmatrix}, \qquad (8)$$

The transformation of three-phase instantaneous values of voltage and current in the reference frame of coordinates is given by the following terms:

$$\begin{bmatrix} v_{s\alpha} \\ v_{s\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix}, \tag{9}$$

and currents :

$$\begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{ca} \\ i_{cb} \\ i_{cc} \end{bmatrix}, \tag{10}$$

The real and imaginary instantaneous power denoted p and q are defined by the following matrix relation:

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_{s\alpha} & v_{s\beta} \\ -v_{s\beta} & v_{s\alpha} \end{bmatrix} \begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix}, \tag{11}$$

By replacing the two-phase voltages and currents by their counterparts phase, we obtain:

$$p = v_{s\alpha} i_{c\alpha} + v_{s\beta} i_{c\beta} = v_{sa} i_{ca} + v_{sb} i_{cb} + v_{sc} i_{cc}, \tag{12}$$

Similarly, for the imaginary power we have:

$$q = v_{s\alpha} i_{c\beta} - v_{s\beta} i_{c\alpha} = -\frac{1}{\sqrt{3}}\left[(v_{sa}-v_{sb})i_{cc} + (v_{sb}-v_{sc})i_{ca} + (v_{sc}-v_{sa})i_{cb}\right], \tag{13}$$

From the expression (11), Asking:

$\Delta = v_{s\alpha}^2 + v_{s\beta}^2$ On a:

$$\begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix} = \frac{1}{\Delta}\left\{ \begin{bmatrix} v_{s\alpha} & -v_{s\beta} \\ v_{s\beta} & v_{s\alpha} \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} \right\}, \tag{14}$$

or:

$$\begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix} = \frac{1}{\Delta}\left\{ \begin{bmatrix} v_{s\alpha} & -v_{s\beta} \\ v_{s\beta} & v_{s\alpha} \end{bmatrix} \begin{bmatrix} p \\ 0 \end{bmatrix} + \begin{bmatrix} v_{s\alpha} & -v_{s\beta} \\ v_{s\beta} & v_{s\alpha} \end{bmatrix} \begin{bmatrix} 0 \\ q \end{bmatrix} \right\} = \begin{bmatrix} i_{c\alpha p} \\ i_{c\beta p} \end{bmatrix} + \begin{bmatrix} i_{c\alpha q} \\ i_{c\beta q} \end{bmatrix}, \tag{15}$$

with:

$$i_{c\alpha p} = \frac{v_{s\alpha}}{\Delta} p \qquad i_{c\alpha q} = -\frac{v_{s\beta}}{\Delta} q, \tag{16}$$

$$i_{c\beta p} = \frac{v_{s\beta}}{\Delta} p \qquad i_{c\beta p} = \frac{v_{s\alpha}}{\Delta} p, \tag{17}$$

The instantaneous power along the axes and can be written:

$$\begin{bmatrix} p_\alpha \\ p_\beta \end{bmatrix} = \begin{bmatrix} v_{s\alpha} i_{c\alpha} \\ v_{s\beta} i_{c\beta} \end{bmatrix} = \begin{bmatrix} v_{s\alpha} i_{c\alpha p} \\ v_{s\beta} i_{c\beta p} \end{bmatrix} + \begin{bmatrix} v_{s\alpha} i_{c\alpha q} \\ v_{s\beta} i_{c\beta q} \end{bmatrix} = \begin{bmatrix} p_{\alpha p} \\ p_{\beta p} \end{bmatrix} + \begin{bmatrix} p_{\alpha q} \\ p_{\beta q} \end{bmatrix}, \tag{18}$$

$$p_{\alpha p} = \frac{v_{s\alpha}^2}{\Delta} p \qquad p_{\alpha q} = -\frac{v_{s\alpha} v_{s\beta}}{\Delta} q, \tag{19}$$

$$p_{\beta p} = \frac{v_{s\beta}^2}{\Delta} p \qquad p_{\beta q} = \frac{v_{s\alpha} v_{s\beta}}{\Delta} q, \tag{20}$$

From the expressions (12), we can write:

$$p = p_{\alpha p} + p_{\beta p} + p_{\alpha q} + p_{\beta q} = p_{\alpha p} + p_{\beta p}, \tag{21}$$

The instantaneous powers p and q are expressed as:

$$\begin{aligned} p &= \bar{p} + \tilde{p} \\ q &= \bar{q} + \tilde{q} \end{aligned}, \tag{22}$$

with:

$\bar{p}$ and $\bar{q}$: Continuous power related to the active and reactive fundamental component of the current.

$\tilde{p}$ and $\tilde{q}$: Power alternatives related to the sum of harmonic components of current [18], [21].

$$\begin{bmatrix} i_{ha}^* \\ i_{hb}^* \\ i_{hc}^* \end{bmatrix} = \sqrt{\frac{2}{3}\begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \sqrt{\frac{3}{2}} \\ -\frac{1}{2} & -\sqrt{\frac{3}{2}} \end{bmatrix}} \begin{bmatrix} i_{h\alpha}^* \\ i_{h\beta}^* \end{bmatrix}, \tag{23}$$

The diagram in Fig. 5 shows the steps for obtaining the current harmonic components of nonlinear load [20].

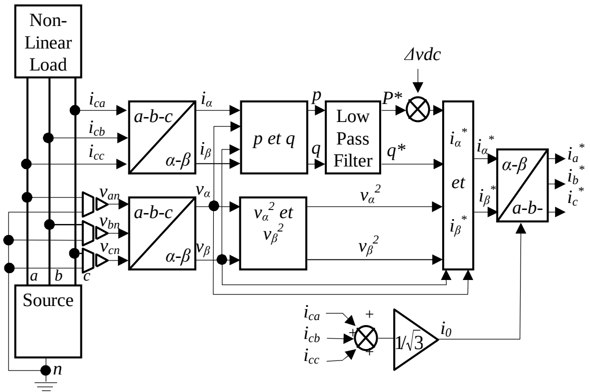

Fig. 5 "P-Q" Algorithm extraction of harmonic currents

B. *Apparent power, reactive power and distortion power [17], [19]*

Steady deformed, it must amend the definition of power so that it reflects the current harmonic:

$$S = \sqrt{P^2 + Q^2 + D^2}, \tag{24}$$

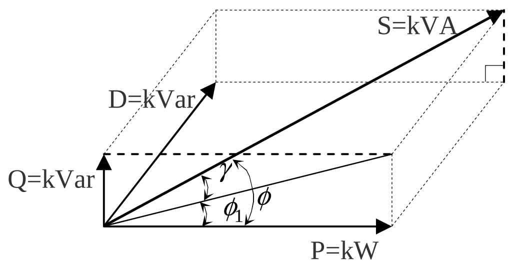

Fig. 6 Vector representation of apparent power

In single phase, if the instantaneous voltage and current are expressed as:

$$\begin{aligned} v(t) &= \sqrt{2} V_{eff} \sin(\omega t) \\ i(t) &= \sum_{n=1}^{\infty} \sqrt{2} I_{n,eff} \sin(n\omega t + \phi_n) \end{aligned}, \tag{25}$$

This is the case for a strong network. Then we have:

$$P = V I_1 \cos(\phi_1), \tag{26}$$

$$Q = V_{eff} I_{1,eff} \sin(\phi_1) , \quad (27)$$

$$S = V_{eff} I_{eff} , \quad (28)$$

$$I_{eff} = \sqrt{I_{1,eff}^2 + I_{2,eff}^2 + I_{3,eff}^2 + \ldots + I_{n,eff}^2} , \quad (29)$$

$$D = V\sqrt{I_{2,eff}^2 + I_{32,eff}^2 + \ldots + I_{n,eff}^2} , \quad (30)$$

C. Total Harmonic Distortion (THD)

Our work focuses on using a parallel active filter, which means we need to calculate the Total Harmonic Distortion of current, as shown in this expression [22]:

$$THD_i = \frac{\sqrt{\sum_{n=2}^{\infty} I_{n(rms)}^2}}{I_{1(rms)}} , \quad (31)$$

V. Fuzzy Logic Controller

Fuzzy logic serves to represent uncertain and imprecise knowledge of the system, whereas fuzzy control allows taking a decision even if we can't estimate inputs/outputs only from uncertain predicates [23], [24]. Fig. 7 shows the synoptic scheme of fuzzy controller, which possesses two inputs: the error (*e*), ($e = i_{ref} - i_f$) and its derivative (*de*), and one output: the command (*cde*).

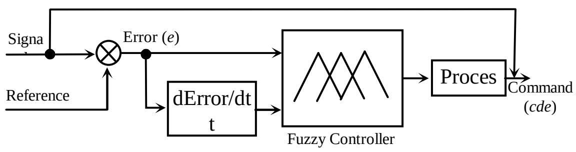

Fig. 7 Fuzzy controller synoptic diagram

Fig. 8 illustrates stages of fuzzy control in the considered base of rules and definitions: fuzzification, inference mechanism, and defuzzification.

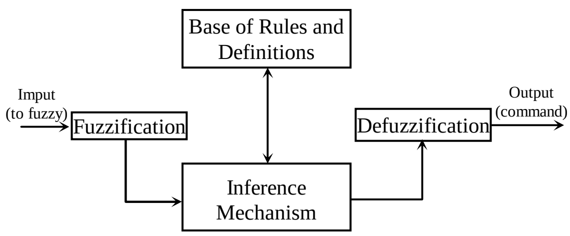

Fig. 8 Fuzzy control construction

This step consists of transforming the classical low pass correctors (LPF) on fuzzy ones. The main characteristics of the fuzzy control are:

- Three fuzzy sets for each of the two inputs (*e*, *de*) with Gaussian membership functions.

- Five fuzzy sets for the output with triangular membership functions.

- Implications using the 'minimum' operator, inference mechanism based on fuzzy implication containing five fuzzy rules.

- Defuzzification using the 'centroïd' method.

Finally, the fuzzy rules are summarized as follows:

1. If (*e*) is zero (ZE), then (*cde*) is zero (ZE).
2. If (*e*) is positive (P), then (*cde*) is big positive (BP).
3. If (*e*) is negative (N), then (*cde*) is big negative (BN).
4. If (*e*) is zero (ZE) and (*de*) is positive (P), then (*cde*) is negative (N).
5. If (*e*) is zero (ZE) and (*de*) is negative (N), then (*cde*) is positive (P).

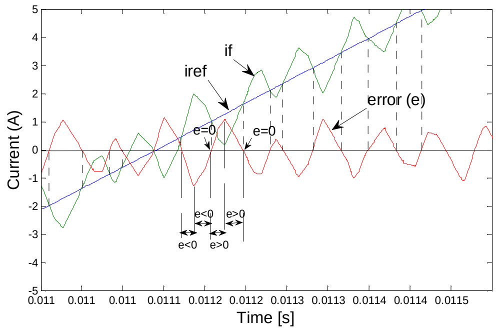

Fig. 9 Fuzzy rules establishment

The fuzzy inference mechanism used in this work is presented as following. The fuzzy rules are summarized in Table I [25].

TABLE I
FUZZY INFERENCE RULES

cde(t)		e(t)				
		NB	**NS**	**Z**	**PS**	**PB**
de(t)	**NB**	NB	NB	NS	NS	Z
	NS	NB	NS	NS	Z	PS
	Z	NS	NS	Z	PS	PS
	PS	NS	Z	PS	PS	PB
	PB	Z	PS	PS	PB	PB

VI. Simulation Result and Analysis

The Simulink toolbox in the Matlab software in order to model and test the system using P-Q algorithm method then fuzzy logic controller. The system parameters values are summarized in Table II.

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TABLE II
SIMULATION PARAMETERS COMMON TO THE APPLICATIONS CONSIDERED

Supply's voltage & frequency	220Vrms, 50 Hz
Line's inductance L_s & resistance R_s	19.4 µH, 0.25 mΩ
DC link's inductance L_{dc} & resistance R_{dc}	20 mH, 6.5 Ω
inductance L_C	1.8 mH
Shunt active filter: DC supply voltage $U_{c1}=U_c/4$ & inductance L_f	 210 V, 2.2 mH
i_{ref} calculation & Control bloc: 2nd order Band Pass Filter BPF, Cut-off frequency f_0 & Damping Factor Zeta ξ 1st order Low Pass Filter: i_f LPF, i_{ref} LPF, Carrier bipolar saw-toothed, signal magnitude and frequency, Switching frequency	 50 Hz, 0.707 K=1, τ = 50e-6 s K=1,τ = 2e-4 s 10, 20 kHz., 5 kHz.

Simulation in this section 3-phase 5-level shunt active power filter response shown here i_s voltage condition sinusoidal. Simulation is carried out for both instantaneous power theory P-Q and fuzzy logic controller.

Fig. 10(a) shows the source peak line-to-neutral voltages of phases "a", "b" and "c" as indicated in v_{sabc}.

Fig. 10(b) shows the distorted source or load currents due to the presence of the nonlinear load and when APFs is not connected as indicated in i_{La}.

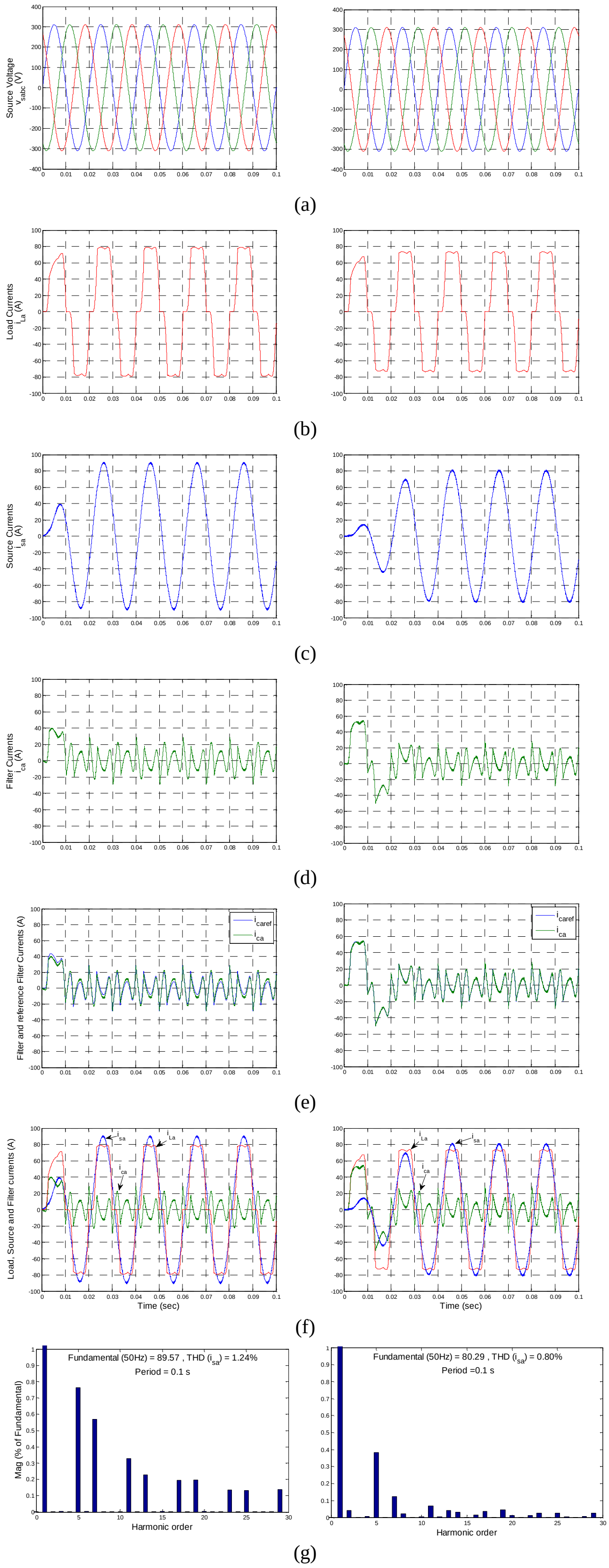
Fig. 10(c) shows the source currents with P-Q method then fuzzy logic are shown in i_{sa} which shows a value for fuzzy controller a little less than the P-Q algorithm and a better sine wave form during the steady state.

Fig. 10(d) shows the compensating current injected into the system by the APFs is illustrated in i_{ca} and similar currents are injected into phases "b" and "c" for both methods.

We see that the filter current i_{ca} well pursues its reference for fuzzy method that the P-Q algorithm as indicated by the two figures in Fig. 10(e).

However, a THDi>5% is unacceptable according to international standards [26]. Indeed, there are distortions in the current wave source. The latter are especially at intersections of i_{La} (current drawn by the nonlinear load) with i_{ca} for nonzero values of these two currents (as indicated in i_{La}, i_{sa} and i_{ca} curves), i.e. when i_{ca} changes direction of growth (up→down or down→up), (see Fig. 10(f), more precisely, it is at di_{ca}/dt. Therefore, to reduce these distortions and make the THDi<5%, we must counter these di_{ca}/dt.

Fig. 10(g) illustrates the performance of Shunt active power filter under balanced sinusoidal voltage condition. THD for P-Q algorithm method is about 1.24% and THD for fuzzy logic controller is 0.80%.



Using P-Q control strategy *Using Fuzzy Logic controller*

Fig. 10. Comparison results between the PQ method and the fuzzy controller for an Active Power Filter shunt 5-Level

VII. Conclusion

The THD measure in the presence of a controlled Shunt Active Power Filter is within the IEEE-519 harmonics standard.

The results obtained in this modest work allow us to visualize the effectiveness of an active power filter shunt (APFs) using a P-Q algorithm then a fuzzy controller.

In fact, the harmonic distortion (THD) drops after using the parallel active filter from 19.20% to 1.24% for the P-Q algorithm method and to 0.80% for the fuzzy logic controller. Thus the power factor has been fixed, that is to say voltage and current became almost in phase.

Summarizes that the Fuzzy Logic controlled based APFs demonstrates a better dynamic behavior than conventional algorithm method P-Q. It does not require any mathematical model of the system and can also work with imprecise inputs.

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